MECHANICAL AND STRUCTURAL PROPERTIES OF BASALT FIBRE AND NYLON ROPE FIBRE INCORPORATED CONCRETE

Bincy Thankachan[1], M.Tech, Department of Civil Engineering, Ilahia College of Engineering and Technology, APJ Abdul Kalam Technological University.

Biby Aleyas[2], Assistant Professor, Department of Civil Engineering, Ilahia College of Engineering and Technology, APJ Abdul Kalam Technological University

ABSTRACT

Growing public environmental awareness leads to an increased focus on utilizing green and sustainable materials in infrastructure construction. Basalt fibers (BFs) are promising construction materials due to their eco-friendly merits and excellent mechanical properties. In this study, the incorporation of basalt fiber and nylon rope fiber has been found to have certain properties which can be useful in the construction. Basalt fibers are produced from basalt rocks by melting them and converting the melt into fibers. Basalts are rocks of igneous origin. The aim of the project is to develop a sustainable concrete with improved strength, durability and having less maintenance by utilizing Basalt fiber and nylon fiber. For mechanical strength properties, compressive strength, split tensile strength and flexural strength tests were conducted to find out the optimum usage of additive materials with proportions of 0.00% 0.50%, 1.00% and 1.50% of weight of cement and for durability, sulphate resistance and chloride resistance test were performed. There was a significant increase in compressive strength, split tensile strength and flexural strength of 19.24%, 23.00% and 20% respectively with the addition of 1.00% basalt fibers and nylon rope fibers. Furthermore, numerical study using ANSYS Workbench (version 2023 R1) was performed to findout deformation behavior of basalt fiber and nylon waste rope fiber incorporated RC beam with various percentages of BFWRF under gradually applied compressive load. The results demonstrate significance of BFWRF incorporation to concrete to achieve sustainability without compromising performance.

Keywords: *Basalt fiber and Nylon rope fiber, Mechanical property tests, Durability tests, Numerical study*

INTRODUCTION

Generation and propagation of cracks in concrete is a crucial issue in concrete structure. It affects both the strength and durability of concrete structures. Fiber reinforced concrete (FRC) is a concrete mix that contains short discrete fibers that are uniformly distributed and randomly oriented. Fiber material can be steel, cellulose, carbon, polypropylene, glass, nylon, and polyester. The amount of fibers added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibers) termed typically ranges from 0.1 to 3%. The randomly distributed discontinuous fibers bridges across the cracks and improves the load carrying capacity in the post-cracking stage.

The manufacture of basalt fiber requires the melting of the quarried basalt rock to about 1400 °C. They have a high elastic modulus, resulting in an excellent specific tenacity that is three times that of steel. The continuous basalt fibers derived from basalt rock have proven technical characteristics and performance specifications.

The fibers resulting from the waste nylon rope can be used to reinforce concrete to avoid the negative impact of the waste on environment and recycling them to valuable materials. Different percentages of locally available waste rope fibers (WRF) shows variation in mechanical and structural properties of concrete. The incorporation of basalt fiber and waste nylon rope fiber to concrete effect the certain properties of both fresh and hardened concrete such as workability, compressive strength, tensile strength, impact resistance, durability etc.

In numerical study using ANSYS software, FEM analysis is used for analyse the behavior of RC fixed beam under gradually applied compressive load.

OBJECTIVES

- To study the effect of combination of Basalt fiber and nylon rope fiber on cement concrete of M25 grade by analytical tests.
- To find the optimum dosage of turn BF&WRF getting maximum compressive strength.
- To compare the performance with that of conventional concrete of M25 grade.
- To conduct a numerical study on the response of plain and BFWRF reinforced concrete beam using ANSYS software.

METHODOLOGY

Detailed methodology of the current study is shown in figure 3.1. This project work initially conducted preliminary tests to find out the properties of materials for mix preparation. The optimum percentage of basalt fiber and nylon rope fiber with the proportions of 0.00%, 0.50%, 1.00% and 1.50% of total weight of concrete is determined by experimental study. By conducting durability studies, sulphate resistance and chloride resistance properties of concrete specimens are determined. Numerical study using ANSYS software is used for analyse the behavior of RC beam with different proportions of basalt fiber and nylon fiber. Mainly, in numerical study the deformation of BFWRF reinforced concrete beam under gradually applied compressive load is studied.

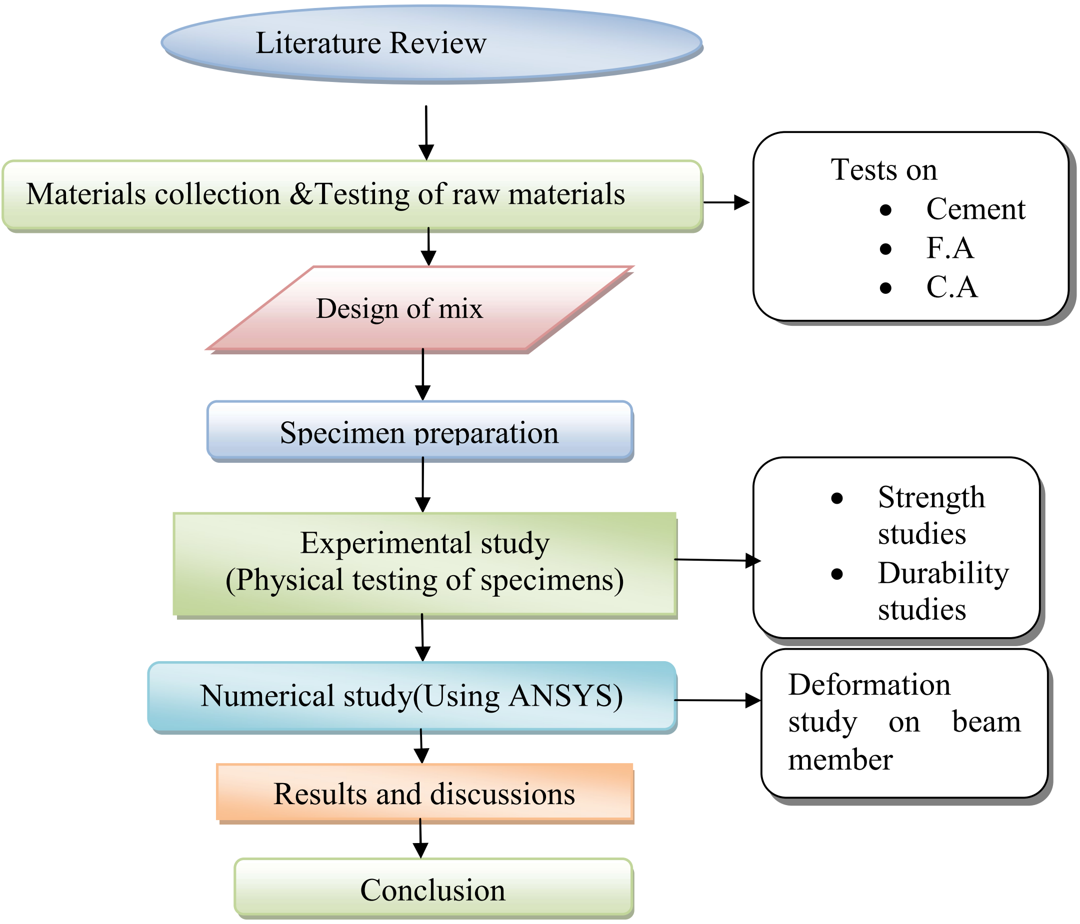

Fig 3.1 Detailed methodology

MATERIAL PROPERTIES

Specific gravity test is conducted for aggregates. For cement, specific gravity, consistency, fineness and initial setting time tests are conducted. The results are tabulated in table 4.1

Fine aggregate

The fine aggregate used in the experiment was locally available manufactured sand (M-Sand) which got through processing the metal quarry dust. The specific gravity of fine aggregate is 2.65 which confirm to IS 2386:1963 Part III. The grain size analysis was also performed and the fine aggregate belongs to Zone I as per IS 383:1987.

Coarse aggregate

The coarse aggregates of nominal maximum size of 20 mm are used in the experiment. The specific gravity of coarse aggregate is obtained as 2.75 which confirm to IS 2386:1963 Part III.

Cement

In the experiment, Portland Pozzolona Cement 53 grade was used. The cement used was tested as per IS 4031:1988. Cement has a specific gravity of 3.2, standard consistency of 30%, initial setting time of 45 minutes and fineness of 7%.

Mixing water

Potable water confirming to IS 456 was used for mixing and curing of specimens throughout the experimentation. It is clear and apparently clean, and does not contain any substances at excessive amounts that can be harmful for making concrete.

The properties of materials used for design of mix shown in table 4.1.

Table 4.1 Properties of raw materials

Sl no.	Material	Test	Obtained value	Allowable limits
1.	Cement	1) Specific gravity	3.2	2.9 - 3.2
		2) Consistency limit	30%	25% - 35%
		3) Fineness	7%	≤10%
		4) Initial setting time	45 min	>30 min
2.	Coarse aggregate	1) Specific gravity	2.75	2.6 – 2.8
3.	Fine aggregate	1) Specific gravity	2.65	2.5 – 2.8

Basalt fiber

Basalt fiber obtained from market is used for experimental investigations. For this study, basalt fiber of 10 mm long is taken. Properties of basalt fiber are given in Table 4.2 and Table 4.3.

Fig.4.1 Basalt fiber

Table 4.2 Properties of Basalt fiber

Sl: No:	Properties	Values
1	Cross Section	Rectangular
2	Thickness/Diameter (mm)	0.10
3	Length (mm)	10
4	Aspect Ratio	7-20

Table 4.3 Standard values of basalt fiber taken from journal

Sl: No:	Properties	Values
1	Density (kg/m^3)	2700
2	Young Modulus (GPa)	50
3	Tensile Strength (MPa)	200
4	Specific Gravity	2.70
5	Elongation (%)	1.5- 3.1

Nylon rope fiber

Nylon rope fibers obtained from the nylon waste rope is used for experimental investigations. For this study, nylon waste rope cut in to average length of 15 mm is taken. Properties of WRF are given in Table 4.4and Table 4.5

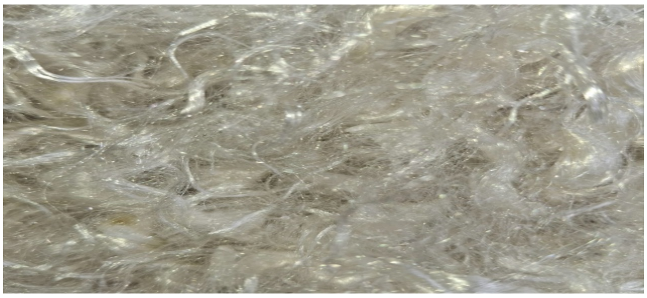

Fig.4.2 Nylon fiber

Table 4.4 Properties of Nylon fiber

Sl: No:	Properties	Values
1	Cross Section	Circular
2	Thickness/Diameter (mm)	0.19
3	Length (mm)	15
4	Aspect Ratio	79

Table 4.5 Standard values of basalt fiber taken from journal

Sl: No:	Properties	Values
1	Density (kg/m^3)	1140
2	Young Modulus (GPa)	2.60
3	Tensile Strength (MPa)	600
4	Specific Gravity	1.14
5	Elongation (%)	15-28

EXPERIMENTAL TEST RESULTS AND DISCUSSIONS

WORKABILITY

The BF &WRF inclusion decreases the workability of the concrete and it is due to the interfacial bond between cement pastes and fibers in concrete limits the dispersion and movement of the cement paste and increases the viscosity of the mixtures. As the fiber content increases, the capacity of the interfacial bond between the cement paste and the fibers becomes flexible as the additional fibers consume the cement paste to cover it. Table 5.1 tabulated the workability of concrete with BF &WRF with demonstration in figure 5.1.

Table 5.1 Slump value of BFWRF mixes

Sl.No.	Specimen	Notation	Slump value in mm
1	Conventional mix	BF0.00WRF0.00	80
2	BFWRF - 0.50%	BF0.50WRF0.50	76
3	BFWRF - 1.00%	BF1.00WRF1.00	69
4	BFWRF - 1.50%	BF1.50WRF1.50	65

Fig. 5.1 Concrete mix preparation

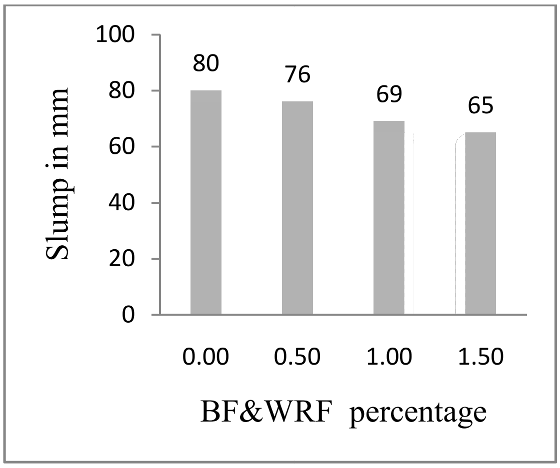

Fig. 5.2 Workability results of BFWRF mixes

COMPRESSIVE STRENGTH

From the test results tabulated on table 5.2, it can be seen that when BFWRF added to concrete mix the compressive strength increases significantly. The optimum value obtained by addition of 1% BFWRF fibers by weight of the concrete. Beyond 1% the strength value is found to be decreasing. There is an increase of 19.24 % compressive strength in 28th day when compared with conventional concrete. Increase in compressive strength is due to the crack arresting properties of the fibers.

Fig.5.3 Compressive strength test set up

Three specimens with different percentage of BFWRF were tested for compressive strength. The results are given in Table 5.2.

Table 5.2 Compressive strength test result

Mix Id	Load value (kN)			Compressive Strength (N/mm^2)
	Cube 1	Cube 2	Cube 3	
BF0.00WRF 0.00%	630	620	620	27.70
BF0.50WRF 0.50%	650	660	640	28.88
BF1.00WRF 1.00%	740	750	740	33.03
BF1.50WRF 1.50%	670	680	660	29.77

Fig.5.4 shows the compressive strength of specimens with different BFWRF percentages

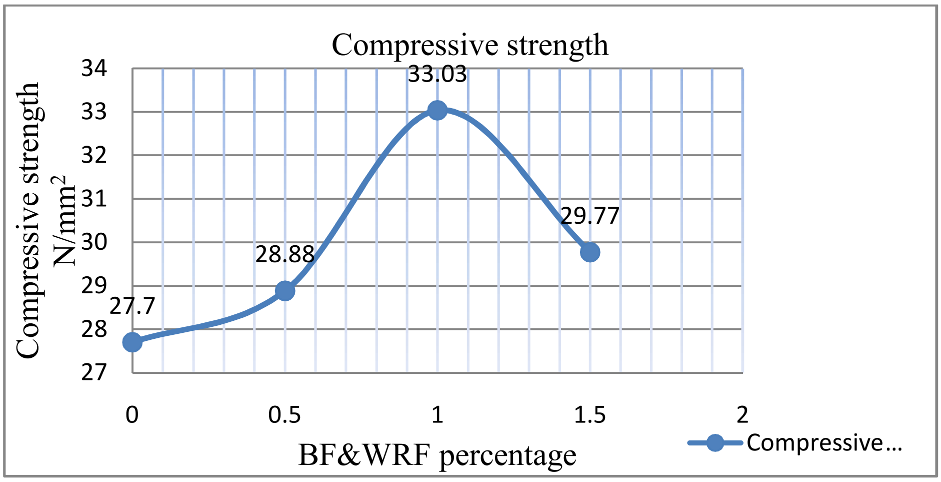

Fig.5.4 Compressive strength vs BFWRF percentage

SPLIT TENSILE STRENGTH

From the test results tabulated on table 5.3 and graph shown in fig.5.6, it can be seen that when BFWRF is added to concrete mix the split tensile strength increases. The optimum value obtained by addition of 1% BFWRF by weight of the cement content. Beyond 1 % the strength value is found to be decreasing. There is an increase of 23.00 % split tensile strength in 28th day when compared with conventional concrete. The fiber in concrete bridges the crack and controls the widening. Also it redistributed loads at crack.

Fig.5.5 Split tensile strength test set up

Three specimens with different percentage of BFWRF were tested for split tensile strength. The results are given in Table 5.3 and fig.5.5 shows split tensile strength test setup.

Table 5.3 Split tensile strength test result

Mix Id	Load value (kN)			Split tensile Strength (N/mm^2)
	Cylinder 1	Cylinder 2	Cylinder 3	
Conventional Concrete	245	240	235	3.39
BF0.50%WRF 0.50%	240	260	255	3.60
BF1.00%WRF 1.00%	305	280	300	4.17
BF1.50%WRF 1.50%	280	270	270	3.86

The fig.5.6 shows the split tensile strength of specimens with different BFWRF percentages.

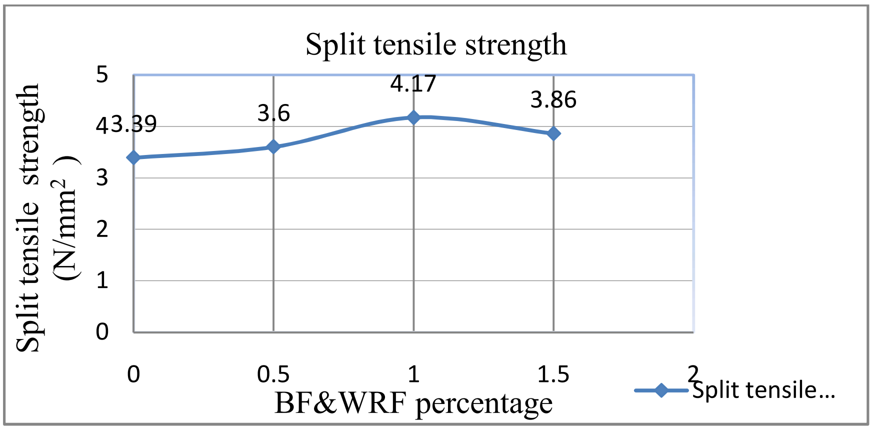

Fig 5.6 Split Tensile strength vs BFWRF percentage

MODULUS OF ELASTICITY

From the test values obtained from experiment, stress strain curves were plotted as shown in fig 5.7 and modulus of elasticity values were calculated and tabulated on table 5.4.According to the result, it can be seen that addition of 1.00% basalt fiber and nylon fiber to concrete the modulus of elasticity is increases to 23.295 N/mm2 and then further addition decreases the value. It is because the addition of steel fiber into concrete could improve the ductile property of the concrete.

The stress-strain graph of M25 concrete mix with different percentages of turn BFWRF are given in Fig.5.8. Modulus of elasticity of each specimen is shown in Table 5.4

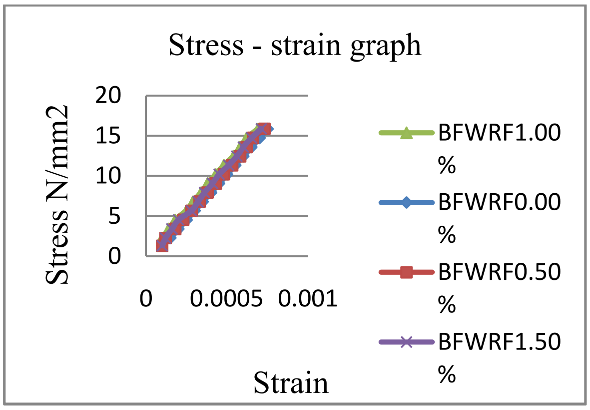

Fig. 5.8 Stress strain curves

Table 5.4 Modulus of elasticity test result

Specimen	Modulus of elasticity (MPa)
Conventional Concrete	21632
BF0.50%WRF 0.50%	22635
BF1.00%WRF 1.00%	23295
BF1.50%WRF 1.50%	23160

FLEXURAL STRENGTH

The change in flexural strength with respect to different percentages of BFWRF is represented in table 5.5 and shown in fig.5.9 shows that maximum Flexural Tensile Strength was for 1% of BFWRF reinforced concrete. Flexural strength decreases with increase in percentage of BFWRF.

Table 5.5 Flexural strength test result

Specimen	Flexural strength (N/mm^2)
Conventional Concrete	4.50
BF0.50WRF 0.50%	4.80
BF1.00WRF 1.00%	5.40
BF1.50WRF 1.50%	5.10

The graph between flexural strength and different percentages of BFWRF shown in Fig.5.10 and flexural strength of each specimen is shown in Table 5.5

Fig.5.9 Flexural strength test set up

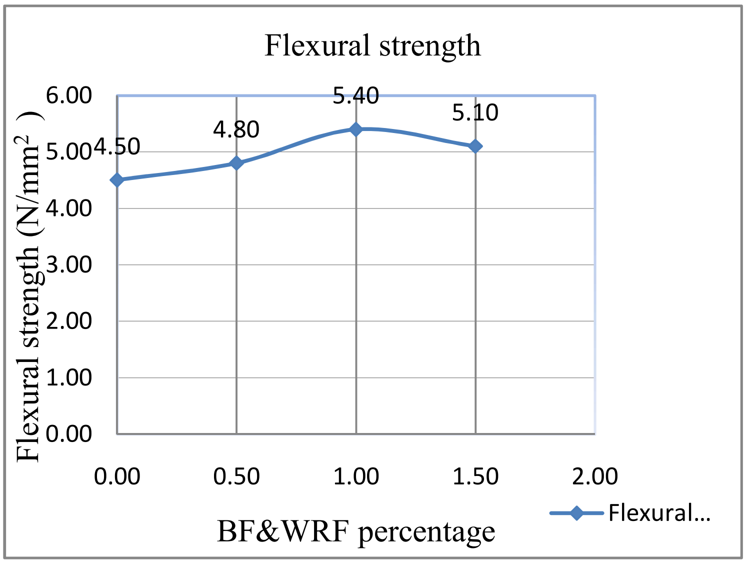

Fig.5.10 Flexural strength vs BFWRF percentage

SODIUM SULPHATE RESISTANCE OF CONCRETE

The pozzolanic activity of the pozzolanic material included in PCC makes it bind with free lime (calcium hydroxide) released in the hydration of Portland cement. The pozzolana and calcium hydroxide combine in cementitious compounds utilizing the calcium hydroxide so that it is no longer available for reaction with sulphates. This prevents the formation of gypsum. The pozzolanic material and calcium hydroxide reaction causes the formation of cementitious compounds that block the bleed channels and capillary pores in the concrete making it impervious to aggressive dissolved sulphates. Since the sulphates cannot combine with cement aluminates, ettringite cannot occur.

Since the PPC is used for this study, pozzolanic material in the cement provides the sulphate resistance properties to the concrete. There was significant sulphate resistance properties observed on the test conducted on BFWRF reinforced concrete specimen. According to the values in the Table No.5.9 and Table No.5.10, BFWRF of 1% provides better sulphate resistance properties to the concrete.

Table 5.6 Percentage decrease of Compressive Strength (Sulphate Resistance)

Type of concrete	28 day strength (N/mm^2)			56 day strength (N/mm^2)		
	Water cured	Na_2SO_4 cured	% of decrease	Water cured	Na_2SO_4 cured	% of decrease
BF0.00WRF 0.00%	27.70	25.30	8.66	27.80	25.19	9.39
BF0.50WRF 0.50%	28.86	26.78	7.20	28.86	26.58	7.90
BF1.00WRF 1.00%	32.89	30.62	6.90	32.95	30.48	7.40
BF1.50WRF 1.50%	29.85	27.56	7.67	30.12	27.53	8.59

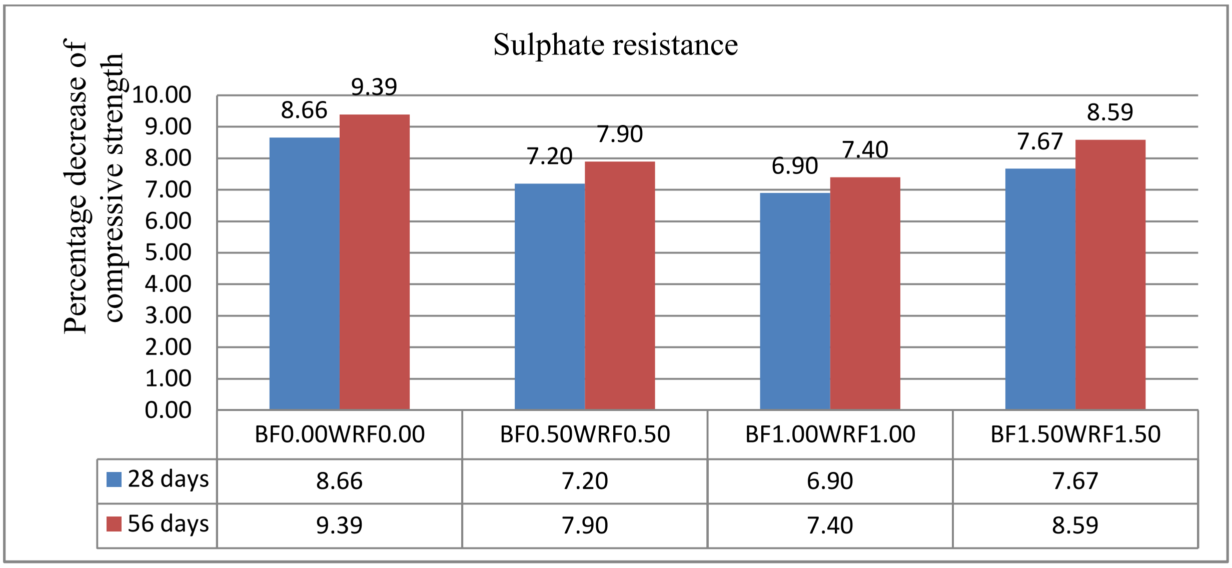

Fig. 5.11 Percentage decrease of Compressive Strength (Sulphate Resistance)

Table 5.7 Percentage decrease of Weight (Sulphate Resistance)

Type of concrete	28 day weight(kg)			56 day weight(kg)		
	Water cured	Na_2SO_4 cured	% of decrease	Water cured	Na_2SO_4 cured	% of decrease
BF0.00WRF 0.00%	8.65	8.15	4.67	8.65	8.14	5.85
BF0.50WRF 0.50%	8.63	8.23	4.63	8.67	8.18	5.65
BF1.00WRF 1.00%	8.66	8.27	4.50	8.69	8.22	5.40
BF1.50WRF 1.50%	8.65	8.25	4.62	8.64	8.15	5.67

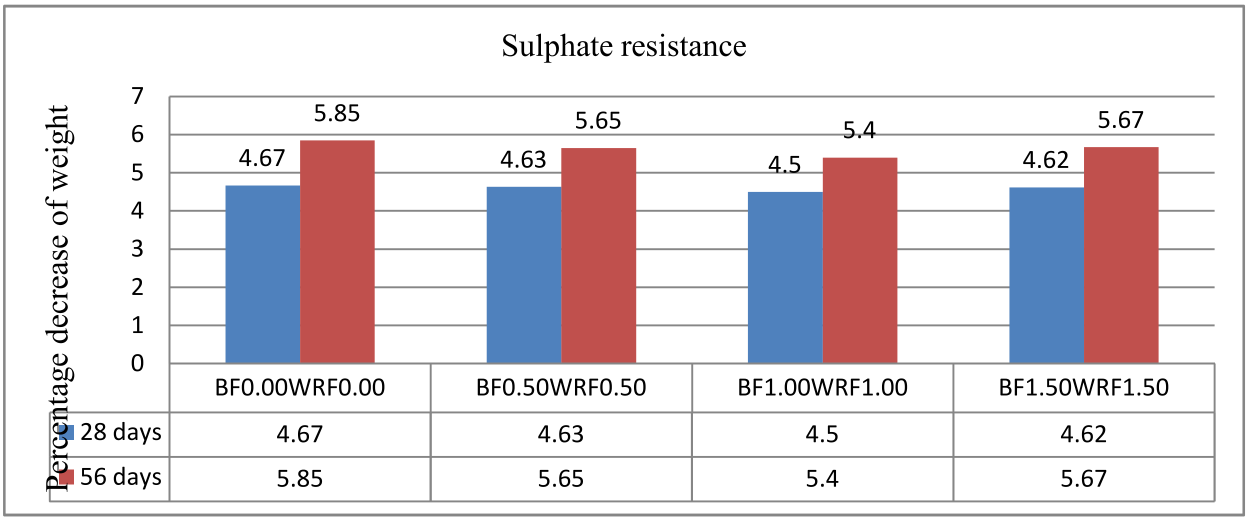

Fig. 5.12 Percentage decrease of Weight (Sulphate Resistance)

CHLORIDE RESISTANCE

As the duration of concrete exposure in hydrochloric acid solution increases, the weight loss decreases in the initial stages. From the results of a 28 days chloride attack, it is clear that the weight loss gradually decreases with the addition of BFWRF. This may be due to the resistance offered by BFWRF against the disintegration due to penetration of chloride ions. Table 5.8shows the variation in compressive strength before and after chloride attack for the age of 28 and 56 days. The compressive strength losses are represented in figure 5.13.

As the duration of concrete exposure in hydrochloric acid solution increases, the compressive strength loss decreases. From the results of 28 days of chloride attack, it is clear that the compressive strength loss gradually decreases with the addition of BFWRF. As the duration of concrete exposure in hydrochloric acid solution increases it was observed the same pattern in weight loss.

Table 5.8 Variation in weight of cubes due to chloride attack

Specimen	Percentage weight difference in %	
	28 days	56 days
BF0.00WRF 0.00%	6.22	6.65
BF0.50WRF 0.50%	5.86	6.12
BF1.00WRF 1.00%	5.80	6.10
BF1.50WRF 1.50%	5.90	6.12

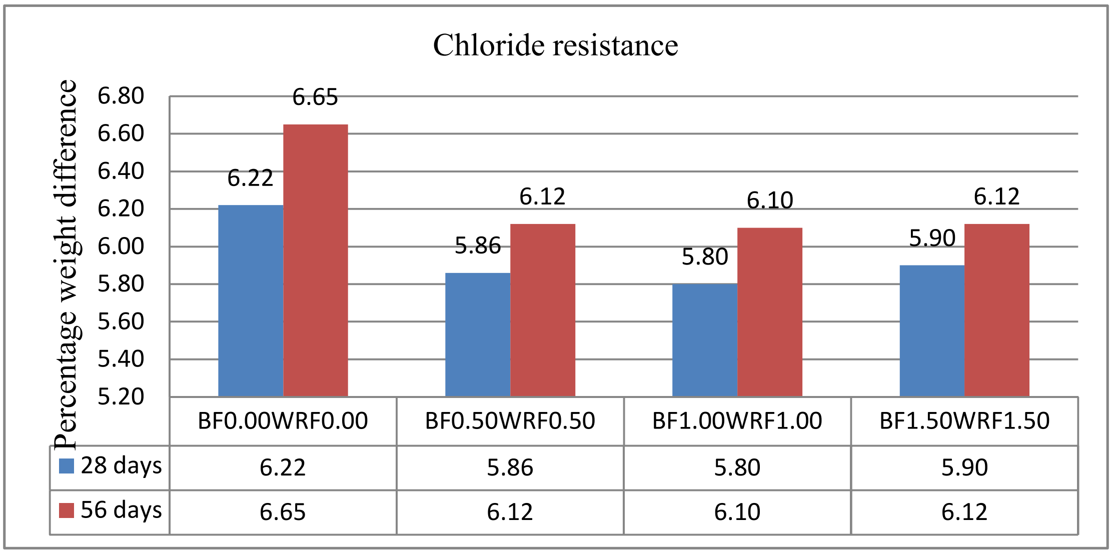

Fig 5.13 Effect of chloride on weight loss in cubes

Table 5.9 shows the variation in compressive strength before and after chloride attack for the age of 28 and 56 days. The compressive strength losses are represented in figure 5.14

Table 5.9 Variation in compressive strength of cubes due to chloride attack

Specimen	Percentage Difference in Compressive Strength of Cube in N/mm²	
	28 days	56 days
BF0.00WRF 0.00%	9.56	9.32
BF0.50WRF 0.50%	8.62	8.80
BF1.00WRF 1.00%	8.35	8.28
BF1.50WRF 1.50%	8.82	8.75

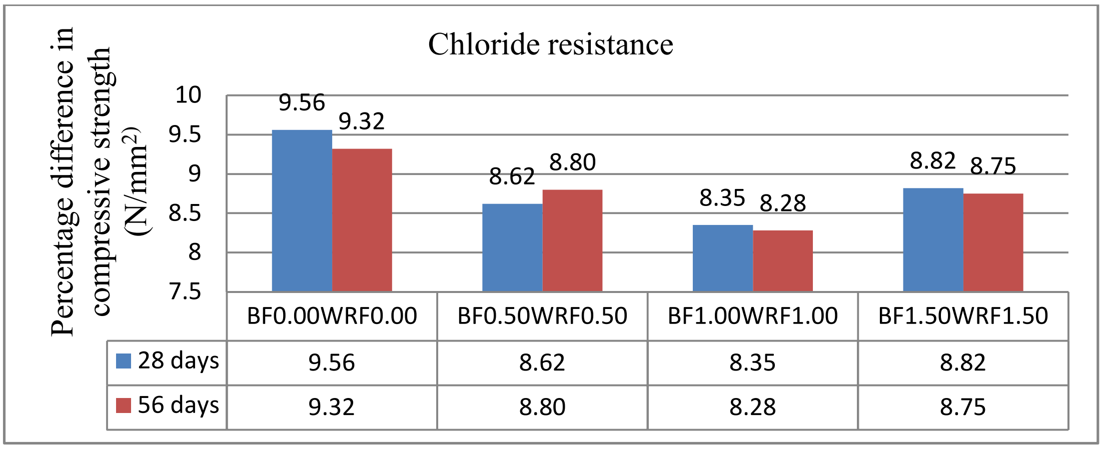

Fig 5.14 Effect of chloride on compressive strength of cubes

NUMERICAL STUDY RESULT

The ANSYS Design Modeler was used to model the beam with the specified dimensions. There is a phenomenal increase in the resistance to deformation of beam under gradually increasing compressive load with the addition of BFWRF. With 1.00% fibre content, the resistance to deformation increased maximum. The minimum resistance observed on conventional beam.

Table 6.4 Maximum deformation

Designation of beam	Maximum deformation in mm
Conventional beam	0.16772
BFWRF0.50%	0.16051
BFWRF1.00%	0.15610
BFWRF1.50%	0.15698

The figure 6.7 shows the total deformation of beam with 0.00% BFWRF under gradually applied compressive load

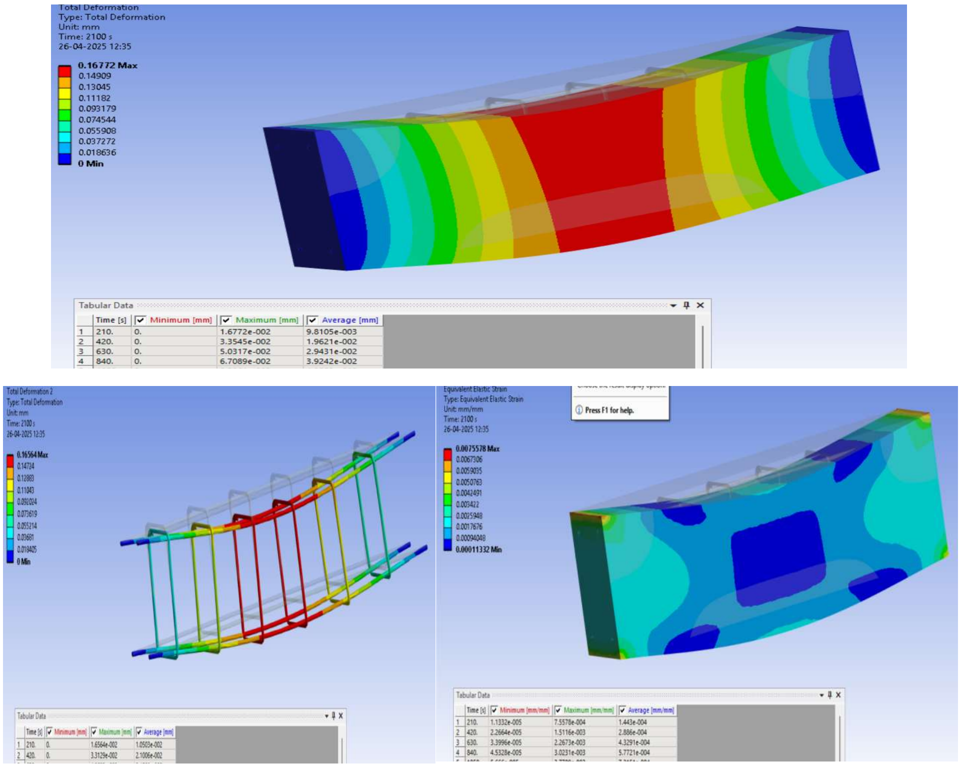

Fig.6.7 Deformation diagram of beam with BFWRF0.00%

The figure 6.8 shows the total deformation of beam with 1.00% BFWRF under gradually applied compressive load

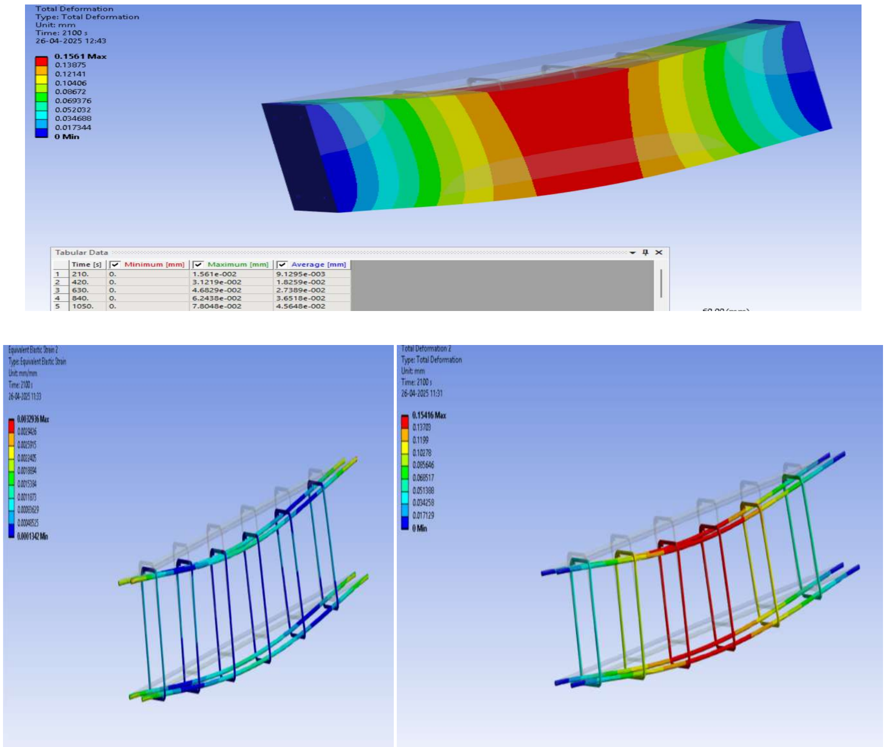

Fig.6.8 Deformation diagram of beam with BFWRF1.00%

There is a phenomenal increase in the resistance to deformation of beam under gradually increasing compressive load with the addition of BFWRF. With 1.00% fibre content, the resistance to deformation increased maximum. The minimum resistance observed on conventional beam. Table 6.5 shows the deformation values against the time step loading.

Table 6.5 Load – deformation values

Load in N	Deformation in mm			
	BF&WRF 0.00%	BF&WRF 0.50%	BF&WRF 1.00%	BF&WRF 1.50%
3150	0.01677	0.01600	0.01560	0.01569
6300	0.03354	0.03210	0.03219	0.03140
9450	0.05317	0.04815	0.04689	0.04700
12600	0.06709	0.06425	0.06244	0.06279
15750	0.08386	0.08025	0.07805	0.07849
18900	0.10063	0.09631	0.09366	0.09419
22050	0.11740	0.11236	0.10927	0.10989
25200	0.13418	0.12841	0.12488	0.12558
28350	0.15095	0.14496	0.14049	0.14128
31500	0.16772	0.16051	0.15610	0.15698

A graph against load and deformation of BFWRF beam with different percentages were plotted and is shown in fig.6.9

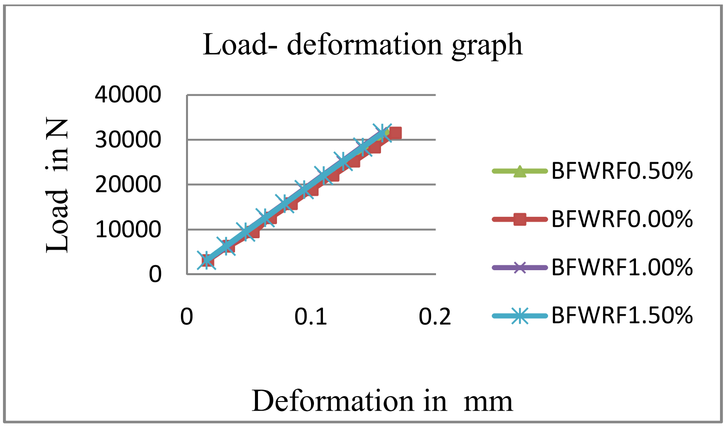

Fig.6.9 Load – deformation graph

CONCLUSIONS

The experimental study and numerical study on basalt fiber and nylon fiber reinforced concrete specimens and beams were done and the following conclusions could be derived from the results.

- The BF &WRF inclusion decreases the workability of the concrete and it is due to the interfacial bond between cement pastes and fibers in concrete. There was a maximum decrease in workability occurred at the addition of 1.5% of basalt fiber and nylon fiber.
- The addition of basalt fibers and nylon fibers into the concrete increased the compressive strength significantly. There was a maximum increase of 19.24 % in compressive strength when 1.00% BF &WRF by weight of cement was added.
- The addition of basalt fibers and nylon fibers into the concrete resulted in an appreciable increase in the tensile strength of concrete. There was a maximum increase of 23.00 % in tensile strength when 1.00 % basalt fibers and nylon fibers by weight of cement were added. This can be attributed to the crack control properties of the basalt fibers and nylon fibers by bridging action.
- Young's modulus of elasticity increases with increase in basalt fibers and nylon fibers content. There was an increase of 28.5 % increase in Young's modulus of elasticity.
- Flexural strength increases with increase in basalt fibers and nylon fibers content up to 1.00 % by weight of cement were added and then decreases. There was an increase of 20 % in Flexural strength.
- There was significant sulphate resistance properties observed on the test conducted on BFWRF reinforced concrete specimen. BF&WRF of 1% provides better sulphate resistance properties to the concrete.
- The compressive strength loss and weight lose due to chloride gradually decreases with the addition of BF&WRF up to 1.00%.
- With 1.00% fibre content, the resistance to deformation increased maximum. The minimum resistance observed on conventional beam

REFERENCES

[1] Zhinjie Huang,Cek Sem So,Wensu Chen ,Paing Min Htet and Hong Hao (2024) Mechanical properties of basalt macro fiber reinforced geopolymer concrete, *construction and building materials*, *(ELSEVIER* 438(2024),136974

[2] D. Akhil Varma, Lakshmi Joseph, Mini K. Madhavan, Karingamanna Jayanarayanan and Alessandro Pegoretti (2024) Strength, durability and finite element analysis of hybrid jute/basalt fiber reinforced polymer confined concrete column under axial compression, *Results in engineering*, 22(2024), 102281

[3] Xutao Zhang , Junyu Wang and Chao Lou(2024) Experimental study on axial tensile properties of basalt fiber reinforced recycled aggregate concrete, *Special Issue of the International Conference on Computational and Experimental Science and Engineering*, 128, 37-39

[4] Shereen Qasim Abdulridha, Mohammad Salah Nasr, Bahaa Hussain Al-Abbas and Zaid Ali Hasan Mechanical and structural properties of waste rope fibers based concrete, *Case Studies in Construction Materials(ELSEVIER), 16 (2022) e00964*

[5] Abdul Siew Choo Chin, Ibrahim G. Shaaban , Joseph P. Rizzuto , Sadaqat U. Khan , Diana Mohamed , Nurul Iman Muhammad Roslan and Azizah Aziz (2024) Predictive model for mechanical properties of hybrid fibres reinforced concrete containing bamboo and basalt fiber, *Structures 61 (ELSEVIER)*, (2024) 106093

[6] Idris Ahmed Ja, Raja Amirul Naquib bin Raja Sazrin , Agusril Syamsir , Naraindas Bheel, Chiemela Victor Amaechi, Teh Hee Min and Vivi Anggraini (2024) Optimization of mechanical properties and impact resistance of basalt fiber reinforced concrete containing silica fume,An experimental response surface assessment, *(ELSEVIER),* 17, 2666-1659

[7] Y.H. Zhang , W.L. Zhong and L.F. Fan (2024) Long term durability investigation of basalt fiber reinforced geopolymer concrete in marine environment, *Journal of Materials Research and Technology (ELSEVIER)*, 31, 593–605

[8] M.M.Hossain, M.R.Karim, M.A.Islam and M.S.Zain (2014) Crack Cronology of Reinforced Concrete Beam Under Impact Loading, *Middle East Journal of Scientific Research,* 3,1990-9233

[9] Maheswaran, C.K, J.K.Dattatreya, P.S.Ambily, and Karansingh,P.R (2014) Investigation on Behaviour of Reinforced Geopolymer Concrete Under Repeated Low Velocity Impact Loading, *IJIRSET*, 3, 2319-8753

[10] ANSYS R1:2023.

[11] IS 10262:2009; Mix design of concrete.

[12] IS 456:2000; Plain and reinforced concrete code of practice.

[13] IS 383:1970; Specification for coarse and fine aggregates from natural sources for concrete.

[14] ACI 549R – 1997; First crack in concrete.

[15] Text book of Finite element analysis by S S Bhavigatti